An Activity Report on Understanding the Effect of Environmental Factors on Human Health and Well-Being

1. Introduction

Human health and well-being are dependent on the interplay of a highly complex array of factors including genetic susceptibilities, environmental interactions and exposures, age, stage of development, stress, and nutritional status. In recent years, national and international interdisciplinary health and Earth science groups have identified a number of high priority, key environment-related public health issues including infectious and vector-borne diseases, air quality, water quality, environmental contaminants, thermal stress (heat waves, cold spells), extreme weather events and disasters, coastal water issues such as harmful algal blooms, famine and nutrition, demographic and economic disruption, ozone depletion, and ultraviolet radiation exposure.

People born in the 21^{st} century, on average, have a life expectancy about twice that of those born just over a century ago. Most of that increase was gained by environmental changes including improved sanitation, purified water, more effective control of disease vectors and reservoirs, cleaner air, safer use of chemicals in our homes, gardens, factories and offices. Continued improvements in quality of life and longevity will require a better understanding of the causes, development and progression of common diseases, especially chronic diseases – and how they relate to environmental factors. For example, why has the incidence of breast cancer climbed in the last 50 years from 1 out of 22 to 1 out of 7? Why did the incidence of asthma increase by 85 percent between 1982 and 1996? What are the relationships between these diseases and environmental factors?

A well-designed global Earth observation system would contribute significantly to providing data and data products on many of these key environmental factors that influence stress (e.g., extreme weather events, noise), nutritional status (price and availability of food), and most importantly exposures (air and water contaminants, pathogens) that directly affect human health and well-being.

2. User Requirements

Over the past several years, there has been significantly growing interest by scientists and decision-makers to better understand the relationships between human health problems and environmental parameters such as temperature, rainfall, wind, soil moisture, solar radiation, vegetation, air and water quality, environmental contaminants, coastal water issues, and land use changes. These data are important for monitoring, risk mapping and surveillance on a large number of different spatial, temporal, and spectral resolutions. A number of high priority requirements have been articulated by national and international environment and health researchers and policy-makers through the IPCC, the US NRC (National Research Council) and IOM (Institute of Medicine), US National Assessment, Arctic Monitoring and Assessment Program (AMAP), NSTC/CISET, National Intelligence Council (NIC), UNEP, WHO, and WMO. The major categories of health and well-being issues, which need data are listed below:

- Epidemiological (land surface) variables useful for infectious and vector-borne diseases, including weather data
- Air quality and pollution

- Water quantity and quality
- Thermal Stress (heat waves, cold)
- Weather Data: Extreme weather data & routine weather data
- UV and near UV radiation levels
- Ocean and Coastal Water Issues (e.g., Harmful Algal Blooms)
- Sources, transport, fate and effects of contaminants in the environment - Atmosphere, oceans, ice, rivers, sediments
- Food Yields and Nutrition
- Biodiversity
- The urban environment & urbanization
- Waste management
- Effect of technological disasters on air, soil, vegetation and water quality
- Transportation
- Energy resources and use
- Noise

Examples of the observational data needed to address these issues are listed in figure 1.

3. Characteristics of Existing Earth Observation Capabilities

Although a fairly extensive suite of earth remote sensing systems has been launched since Landsat-1 (LAND SATellite) in 1972, the use of these systems for human health studies has focused primarily on studies of land surface variables and their application to epidemiological studies. However, remote sensing is also providing useful data for other important health issues such as extreme weather, air pollution, UV radiation, ocean/coastal issues, and contaminant transport. A description of the application of existing remote sensing systems to many of these major health issues follows:

a) <u>Epidemiology – land surface variables</u>

The use of remote sensing for epidemiological studies is based upon the fact that the temporal and spatial distribution of most infectious and vector-borne diseases (as well as their vectors) are dependent upon a complex combination of environmental factors such as temperature, soil type and moisture, humidity, landscape structure, rainfall, vegetation, and water bodies, most of which can be measured, observed, and/or modeled with data from existing remote sensing systems. These environmental variables control the suitability of any site as a habitat for both vectors and diseases as well as their viability, abundance, breeding success, and transmission. Remote sensing contributes valuable data and observations on these environmental variables and provides information for a) categorizing, mapping, and modeling parasite, pathogen, vector, and host habitats, b) observing changes in habitats, c) predicting related changes in host or vector populations, and d) creating risk maps useful for control programs.

The primary remote sensing systems, which have been used for the land characterization aspects of epidemiological studies for infectious and vector-borne diseases, are passive remote sensing systems such as the MSS (Multispectral Scanner), TM, NOAA's Advanced Very High Resolution Radiometer (AVHRR), and the Systeme Pour l'Observation de la Terre (SPOT) of France. High spatial resolution sensors (generally, resolution less than 1km by 1km) include the Landsat series of satellites, beginning in 1972, the SPOT series, initiated in 1986, and, more recently, IKONOS and MODIS (NASA's Moderate Resolution Imaging Spectroradiometer). While these sensors offer higher resolution imagery and have been used for a number of epidemiological studies, factors such as cloud cover, data availability, low temporal frequency, and/or high cost have limited the use of these systems. Low spatial resolution sensors include the NOAA series, operating since 1978, which carry the AVHRR, and the Meteosat series from the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), first launched in 1977, carrying the High Resolution Radiometer (HRR) and designed for meteorological applications.

In addition, USGS land cover data characteristics data and a variety of geospatial data sets (terrain, hydrology, soils, geology, transportation) plus census data are important data sources for epidemiology studies. Disease data sets such as ArboNet are important systems for integration into a GEO system.

b) Extreme Weather and climate-related Events

Extreme weather and climate-related events can have direct and/or indirect effects on all types of human settlements. Weather, climate, and extreme weather-related events like drought and storms, hurricanes, tornados, and cyclones with excessive rainfall, often resulting in serious flooding can create health risks directly through injury, infection, and mortality as well as indirectly from epidemics of waterborne diseases such as cholera and typhoid fever and vector-borne diseases such as malaria and dengue fever. In addition, extreme weather can also impact the health of populations through forced movement of populations, loss of shelter, contamination of drinking water, destruction of infrastructure, loss of healthcare facilities, and loss of food production and associated malnutrition

A wealth of remote sensing resources for weather and climate information is available to urban and rural planners and other decision-makers for addressing environment-related health problems. [This paragraph will provide a summary of some of the systems considered especially useful to studies of health, weather, and climate, but] a more complete description of NASA missions currently in orbit may be found at http://www.gsfc.nasa.gov/indepth/mission_osc.html.

Geostationary weather satellites, developed and launched by NASA for NOAA, and their visible and infrared sensors aboard NOAA's GOES (Geostationary and Polar-Orbiting Weather Satellites) and POES (Polar Orbiting Satellites) series make available views of weather phenomena on both coasts and oceans of the US and South America. NOAA polar orbiting operational weather satellites, such as NOAA-J, K, and L, are providing global measurements along with Europe’s Meteosat, Japan’s Geostationary Meteorological Satellite (GMS), and India’s Insat. NASA’s Tropical Rainfall Measuring Mission (TRMM), a joint mission between NASA and the National Space Development Agency of Japan (NASDA), monitors and studies tropical rainfall and the associated energy release which helps drive global atmospheric circulation, which, in turn, shapes weather and climate around the world. Seawinds, carried on Quickscat, measures winds over the oceans, which are critical in hurricane assessment, and TOPEX/Poseidon (Topography Experiment) and follow-on, JASON, provide sea surface height, a key to ocean circulation and global climate. MODIS and MOPITT (Measurements of Pollution in the Troposphere) on NASA’s Terra spacecraft, monitor a variety of weather and climate parameters such as temperature, clouds, moisture, atmospheric pollutants, and aerosols. The earth’s radiation budget, critical to climate studies, is provided by CERES (Clouds and the Earth’s Radiant Energy System) on TRMM and Terra and ACRIMSAT (Active Cavity Radiometer Irradiance Monitor) measures the total of solar energy, which reaches earth, important to climate and global warming studies.

Some of the other important remote sensing systems that provide weather and climate observations and data which provide useful data and information to health studies are the MISR (Multi-Angle Imaging Spectroradiometer) on Terra (observes temporal changes in dust, clouds, and surface); the U.S. Defense Meteorological Satellite Program (DMSP) and its suite of measurements of such phenomena as clouds, lightning, and rainfall; the Earth Radiation Budget (ERBS) for climate-related processes; UARS (Upper Atmosphere Research Satellite) for energy input, chemistry, and dynamics of the upper atmosphere, and coupling between the upper and lower atmosphere; and TOMS (the Total Ozone Mapping Spectrometer) which provides daily mapping of the earth's atmospheric ozone globally.

c) Air quality/air pollution

Air pollution from both natural and anthropogenic causes is considered to be one of the most serious world-wide environmental-related health problems, and may worsen with changes in the global climate. Fortunately, many existing and planned satellites are devoted to the retrieval of a number of important atmospheric parameters. For gaseous pollutants, there are several low-resolution measurements for global scale mapping (e.g., TOMS, GOME (Global Ozone Monitoring Experiment), MOPITT, Shuttle measurements, future EOS AURA and the European Envisat). For aerosols, the optical thickness may be retrieved by low-resolution sensors (TOMS) for global scale mapping, moderate-resolution sensors (e.g., AVHRR, MODIS, SeaWiFS) for continental to regional scale mapping, and high-resolution sensors (e.g., Landsat, EO-1) for regional to local scale mapping.

d) UV Radiation

Ozone depletion and the associated increases of ground-level ultraviolet radiation are of serious health concern. Excessive ultraviolet radiation (UV) is well known to have a number of harmful effects on humans, such as sunburn and skin cancer, cataracts, and immune system suppression. In addition to ground-based systems for measurement of UV radiation levels, a mature remote sensing system established in 1978 continues to provide daily measurements of UV radiation at the earth's surface on a global basis from the Earth Probe/Total Ozone Mapping Spectrometer (TOMS). This system provides data and information in real time on the web and is used routinely for decision-making and early warning systems as well as for retrospective time series studies using the long-term data sets.

d) Ocean/Coastal issues

Of the key ocean and coastal health-related issues recently defined the most readily-addressed through remote sensing are harmful algal blooms (HABs), certain aspects of biotoxins, the dynamics of infectious diseases, pollutants, and extreme weather hazards. As with the atmosphere, remote sensing of the ocean for health purposes is best combined with in situ instruments (moored, buoys, shipboard, or surface-mounted) to characterize the dynamics of this complex three-dimensional, patchy system. The primary systems useful for observing the oceans for health purposes are sensors to measure ocean color, sea surface temperature, wave height, and sea surface height. Observing ocean color is a means of determining ocean clarity and, therefore, enables detection of algal blooms, sediments, nutrients, and some contaminants important to studies and monitoring of harmful algal blooms, biotoxins, certain pathogens, and pollution. The systems most useful for these applications are SeaWiFS, launched in 1997 and the higher-resolution MODIS, launched in 1999. Sea surface temperature can be used for observing ocean circulation and ocean currents which transport algal blooms, pollutants and pathogens, and can be obtained from the NOAA, AVHRR, and MODIS thermal bands.

NOAA and some coastal states have Harmful Algal Bloom monitoring programs, which are used to prevent illness and to predict development and movement. Ground-based monitoring programs for bacterial contamination in water and seafood are carried out by some agencies and states

Winds over the ocean, which are critical for hurricane and storm assessment, are monitored by Seawinds aboard Quickscat. Sea surface height and wave height are both derived from altimetry, most commonly from TOPEX/Poseidon, operated by NASA and France's Centre National d'Etudes Spatiales (CNES) and follow-on, JASON. Sea surface temperature, sea surface height and wave height have been useful in recent studies investigating the relationship between cholera outbreaks in Bangladesh and sea surface temperature, sediment load, phytoplankton abundances, and sea surface height.

e) <u>Contaminant Transport and Deposition</u>

While there is a certain amount of direct tracking of environmental contaminants by remote sensing technologies currently underway (see, for example the section on air quality), there is a diverse suite of existing earth remote sensing satellites routinely observing environmental parameters associated with the atmosphere, oceans, rivers, and sea ice which could be used for more aggressively monitoring the transport mechanisms that move contaminants from place to place. Atmospheric transport, described earlier in this section under the air quality discussion, may best be observed through TOMS, MOPITT, MODIS, SeaWiFS, AVHRR, and Landsat. . To observe movement of rivers, sediments, and, indirectly, associated contaminants, the following systems could be utilized: polar microwave data from Radarsat and Synthetic Aperture Radar (SAR), and visible IR (infrared) data from SeaWiFS, AVHRR, and MODIS. Movements of ocean waters, sediments, algal blooms and some pollutants may be observed through TOPEX/POSEIDON, SeaWiFS, MODIS, and/or AVHRR. Finally, sea ice extent, concentration, motion, and velocity are being monitored by global passive microwave (SMMR, SSM/I), synthetic aperture radar (Radarsat, ERS-1, ERS-2), and polar VIS/IR (MODIS, AVHRR, SeaWiFS). (Radarsat, ERS-1, ERS-2), and polar VIS/IR (MODIS, AVHRR, SeaWiFS).

f) <u>Non-remote Sensing Observations Systems</u>

In order to connect environmental data from remote sensing observation systems seamlessly with human health researchers, service providers, and policy-makers, it is critical that the surveillance and monitoring systems of both the public health and Earth science communities become an integral part of a larger system - governed by interoperability - to achieve geospatial mobilization and readiness for major health issues. Thus, a process should be developed to include this system as many of the health surveillance and monitoring systems, which presently exist, such as NIH, NCI, CDC (e.g., ArboNET), NOAA (e.g., HAB network), DOD, EPA, National Center for Health Statistics, Indian Health Services, states, local governments, international systems (e.g. WHO, Arctic Monitoring and Assessment Program- AMAP, IPCC), and the private sector.

4. Major Gaps and Challenges

In order to create a comprehensive, useful Earth observation system, it is necessary to enable the easy transfer of environmental information to researchers, response communities, and policy-makers. Thus, it is important to develop user-friendly systems for quick access to Earth science data. However, many factors have hindered the use of remote sensing data for health applications. Some of the most important are:

1. Lack of appropriate spatial, temporal and spectral resolution measurements by the current satellite sensors.

2. Lack of good communication and understanding between the remote sensing data producer community and users in the health and environment fields of research.

3. Complexities associated with health and environment relationships due to the diversity and number of variables.

4. Absence of continuous temporal and spatial data sets required for the study of specific diseases or health related problems.

5. Difficult access to data and value -added products due to differences in format, resolution, projection, computer systems and lack of an integrated system with generally accepted standards for unified studies.

6. Cost and limited access to high-resolution satellite remote sensing data.

7. Insufficient technology transfer methods to move from research to operational environments.

Many of these problems are being indirectly addressed as a result of a steady increase in the number and sophistication of satellite remote sensing systems recently or soon to be launched. However, a focused effort is needed to improve the technology transfer and the development of friendly user tools for the mass distribution of data and products. In addition, effective implementation of these systems requires the promotion of both public and private sector use and dissemination of Earth science data/products and effective technology transfer in order to extend the use of the remote sensing agencies' research contribution beyond the traditional science community to be applied to the needs of all levels of government and local users. This, in turn, requires the development of more efficient ways for the diffusion of remote sensing data, value added products, technology and concepts for application of these technologies to public health. In particular, remote sensing data combined with geographic information systems (GIS) and global positioning systems (GPS) are fundamental tools for the planning, analysis, surveillance and intervention in the control and management of infectious diseases outbreaks. To take full advantage of these technologies, they need to be fully integrated with one another in order to benefit the end-user in a timely and cost-effective way.

<u>Additional challenges include the following</u>:

- Reservations by scientific community regarding data sharing – health, plant, animal, and environmental

- Need agreed-upon standards for comparison of disparate sources of data and for establishment of interoperable systems
- Provision of temporal and spatial data with enough parameters to be useful in both static and dynamic models
- Need real-time data
- Need better metadata
- Need uninterrupted time series environmental data – historical and future
- Harmonization of data collected in a laboratory with that for the same environmental agent collected in the natural environment
- Data collected at an appropriate spatial scale to derive relevant regulatory actions/emergency response

5. Interagency and International Partnerships

Due to the multiple factors involved in addressing environmental health issues, scientists from many disparate disciplines are needed to address these issues (disciplines not accustomed to working together). Therefore, to create a successful integrated observation system usable by members of both the environment and health science and policy communities, partnerships among these scientists and stakeholders are essential. Strong partnerships help ensure that the appropriate data sets are collected, integrated, interpreted, and used in the proper fashion. While there are a number of interagency partnerships which exist at this time, it will be critical to make an aggressive effort to develop a system of comprehensive partnerships among agencies, states, and other parties in order to create a useable as well as useful observation system. Also, Federal agencies and partners must encourage consistent practices, interoperability, and information sharing among State and local agencies that gather data.

Examples of existing partnerships include: NOAA/NWS provides forecasts of heat waves to CDC staff who are involved in research on the effects of heat waves and in working with State and Local officials to prevent heat-related morbidity and mortality. Similarly, CDC for its disaster preparedness and response roles relies on NOAA/NWS to predict the location and severity of extreme weather events. NIEHS researchers use EPA data on air and water quality for health effects studies. UCAR/NCAR provides UV exposure data for melanoma studies. University researchers in the U.S. and abroad supported by the NOAA/EPA/NSF/EPRI Program on Climate Variability and Human Health use observational data from NOAA, NASA, CDC, and state and local public health agencies to characterize the link between vector-borne diseases and climate with the goal of developing early warning systems for disease outbreaks. NIAID and NASA have an interagency agreement to support training for African scientists in the use of new technologies for the control of malaria. The purpose of the initial effort was to determine if remotely sensed information could be used to develop predictive models for risk of malaria transmission. Finally, bacterial contamination is monitored by local public health agencies and the same agencies use the data. NOAA and other Federal agencies assist by providing updated methodologies. National databases on bacterial contamination are updated by collecting data from state agencies that, in turn, collect it from the local agencies that made the measurements

6. U.S. Capacity Building Needs

Relatively few individuals presently are able to bridge the gap between the natural sciences (e.g., people that produce and analyze earth observation data) and the health sciences. Clearly the full value of earth observation data being used with health data will not be realized until we have more individuals trained in this specialty. For example, training for both the malaria teams and those charged with developing predictive models for climate and other factors that regulate mosquito vector populations, and therefore, the transmission of the parasite should be a major goal. Education and training for people who design, build, and operate observing systems, who analyze data, and who produce data products is an ongoing need. Conversely, building institutional willingness and capacity in public health to move beyond surveillance and response to prediction and prevention by effectively using observational data in new decision support tools must be a priority. Federal agencies must continue to work with state, local and private sector service providers and authorities to enhance planning and response capabilities.

The need for education and training at all levels in developing countries is as great as the need for equipment to gather and process data. The U.S. should increase capacity for developing country scientists through training programs and collaborative research programs. Examples include the Fogarty International Center at NIH/HHS International Research Training in Environmental and Occupational Health Program, which provides short-term, long-term, degree-oriented and post-doctoral training to developing country scientists in their home countries and in the U.S. It also provides grants for collaborative research between U.S. and developing country scientists through its Health, Environment and Economic Development Program now operating in 11 countries. NASA, NOAA, EPA, and other Federal agencies also have programs for capacity building in related areas and it is recommended that the agencies coordinate existing programs and begin building an across the board capacity building system for training and education at the intersection of environment and health observations, data collection and analyses.

Again, to build a useful observing system for health and well-being purposes, it will be necessary to urge partnerships to integrate observations and data from ground-based and health/social systems. For example, the international aspects of bacterial water quality monitoring are best handled through the World Health Organization or, in the Americas, through the Pan American Health Organization. New partners from the remote sensing and environmental community could contribute useful parameters to those monitoring activities.

It will be important to make special efforts to build appropriate capacity in developing nations where health and well-being problems are often overwhelming. This is a complicated issue, but one which, if a global system is to be successful, must be aggressively addressed. In developing countries, for example, it is not necessarily a lack of knowledge that often prevents enforcement of an issues such as bacterial standards; rather, limited public health funds that are devoted to more pressing problems.

7. Future Earth Observation Systems – Not Yet Deployed

The currently active remote sensing technology with the greatest potential for epidemiological studies is radar, and, in particular, synthetic aperture radar (SAR). This technology could be especially useful because it is capable of operating day or night and can obtain data through clouds. While a number of technical difficulties such as data interpretation, calibration issues, software, and problems related to topography have prevented this technology from widespread use in public health studies to date, the potential for its application to public health issues is great because it would enable collection of information on important parameters such as accurate land cover change characterization, delineation of water bodies and flooding extent, and soil moisture.

The future NPOESS system will have much of the capability of the MODIS instrument. This will provide vegetation, land use variability, surface temperature and some soil moisture capability, along with cloud and aerosol detection. However, the spatial resolution will not be much different from current instruments. We will continue to need the very high spatial resolution sensors if we are to monitor mosquito-breeding sites. For precipitation measurements, the Global Precipitation Mission has great promise, but it is going to be delayed to about the end of the decade for launch. For coastal managers, new remote sensing technologies such as optical detectors, autonomous underwater vehicles and satellite sensors other than SeaWiFS are being developed to detect and track HAB movements in time to take proactive measures to protect public health. Some of this technology has already been incorporated into ongoing testing programs and has allowed for the proactive opening and closing of shellfish harvests and efforts are underway to incorporate successful sensors into regional observing systems.

Finally, there are two promising space-based technologies that could provide data and platform resources for remote sensing applications to health issues: the rich database of Space Shuttle earth imagery, and platform opportunities on the International Space Station (ISS). Since 1981, NASA astronauts on the Space Shuttle have used hand-held cameras to take more than 400,000 photographs of the earth, and all of the imagery is in public domain and several thousands of shuttle images are currently available from the NASA web site http://eol.jsc.nasa.gov. Preliminary results from the analysis of imagery from the Shuttle-Mir missions demonstrate that there is a rich storehouse of information of astronaut-acquired imagery, which would be very useful for health applications. The International Space Station provides a platform for many different types of earth viewing sensors, which can be mounted both internally in the Window Observational Rack Facility (WORF) --an earth-viewing "optical quality" window -- or as external payloads. A major difference (and advantage) between these acquisition methods and other satellite collection methods is the constant presence of astronauts which allows investigators to benefit from a trained human observer, to interact with payloads directly, to respond to episodic events, and to recover malfunctioning payloads for repair and return).

8. Summary

- Higher spatial and temporal resolution. The combination of high spatial resolution and repeat coverage over an area are among the most critical parameters for future instruments, regardless of the channels utilized.
- Affordable data costs. Costs for data must be reasonable if data are to be utilized widely.
- Improved access and use of remote sensing data. Easier access to and use of remote sensing data must be made possible
- More continuous temporal and spatial data sets for disease studies.
- Funding for interdisciplinary (health-environment) research & activities. Presently funds for academic research in this area seem to fall in a gap between NSF, NIH and other agencies. Likewise government agencies wishing to pursue collaborative research find it difficult to obtain agency funding since it is perceived to fall outside the core mission of the agency (the synergistic effects of collaboration seem to be difficult to justify to agency budget analysts). A funding source that encourages interagency collaborative research and applications activities is recommended.
- Formation of a distributed federation of data bases (including ground based and health data. The collection of quality data to predict changing environmental conditions must be expanded. Provisions for sharing environmental and human, plant, and animal data on a timely basis in a distributed federation of databases designed to make existing information more accessible need to be put in place. Standards to compare disparate sources of data should be developed. Adequate metadata must be developed for all data collected. The use of bioinformatics and state-of-the-art information technology capabilities (e.g., geospatial, visualization) to increase understanding of the effects of environmental factors on human health and well-being must be encouraged. Models that

can handle multidisciplinary data, including a national capability in infectious disease modeling, must be further developed.

- Interoperability. Coordinated data management and interoperability across agencies and user groups are essential elements for a system of Earth observation systems for a health and environment system of georeferenced data bases.
- A surveillance program to monitor the presence of infectious diseases. This should include disease vectors and natural reservoirs, for humans, animals and plants.
- A surveillance and monitoring program for air pollution episodes.
- Development of sensors for HABs and their toxins. An example of this is the NCCOS center for Sponsored Coastal Ocean Research (CSCOR), through the ECOHAB and MERHAB programs, which supports research to develop rapid and highly selective tools and sensors for the monitoring and testing of harmful algal blooms. These prototype tools are aiding in the assessments of public health impacts of harmful algal blooms, the detection of toxins and harmful species at low concentrations/levels, and to understand to effects of sub-lethal exposure to toxins. New remote sensing technologies such as optical detectors, autonomous underwater vehicles and satellite sensors are also being developed to detect and track HAB movements in time for coastal managers to take proactive measures to protect public health. Some of this technology has already been incorporated into ongoing testing programs and has allowed for the proactive opening and closing of shellfish harvests and efforts are underway to incorporate successful sensors into regional observing systems.
- Establishment of entities for decision support and management decision-making of the IWGEO system for application to real-world problems. For example, the NCCOS center for Sponsored Coastal Ocean Research (CSCOR) supports coastal management decisions through peer-reviewed research by funding comprehensive regional coastal ecosystem studies that integrate modeling, retrospective, broad-scale, and process studies to develop a pro-active predictive capability to safe-guard coastal living resources and the public health. CSCOR studies focus on the linking of physics and biology through the development of a suite of coupled physical-biological ecosystem models to enable timely ecological forecasts for a variety of key management concerns such as harmful algal blooms, hypoxia, fisheries, and cumulative coastal impacts. These models will ultimately be transferred to state and federal management entities and incorporated into regional observing systems.
- Develop improved and faster indicators of the human disease potential of recreational and shellfishing waters.